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Biological Diversity, Ecology, and Global Climate Change

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Worldwide climate change and loss of biodiversity are issues of global scope and importance that have recently become subjects of considerable public concern. Unlike classical public health issues and many environmental issues, their perceived threat lies in their potential to disrupt ecological functioning and stability rather than from any direct threat they may pose to human health. Over the last 5 years, the international scientific community and the general public have become aware of the implications that atmospheric warming might have for world climate patterns and the resulting changes in the persistence, location, and composition of ecosystems worldwide. At the same time, awareness of the magnitude of current and impending losses of the world's biological diversity has increased. Human activites are currently responsible for a species loss rate that is the most extreme in millions of years, and an alarmingly increasing rate of transformation and fragmentation of natural landscapes. We are just beginning to grasp the meaning of this loss in terms of opportunity costs to human society and the less quantifiable losses associated with simplification of natural ecosystems. In the case of both global warming and reduction of biological diversity, man is affecting nature in an unprecedented fashion, on a global scale, and with unpredictable and frequently irreversible results.

Introduction

While a few atmospheric scientists have warned for decades that continued increase in anthropogenic emissions of greenhouse gases will irrevocably change the composition of the earth's atmosphere, it has only been recently that research results, particularly analysis of the air trapped in polar ice cores, have documented that such changes are in fact underway.

Over the last 5 years, the international scientific community and the general public are also becoming aware of the implications that such atmospheric warming might eventually have for world climate patterns and the persistence, location, and composition of ecosystems worldwide.

At the same time, awareness of the magnitude of current and impending losses of the world's biological diversity has increased. Human activities are currently responsible for a species loss rate that is the most extreme in the last 65 million years (*1*). We are just beginning to grasp the meaning of this loss in terms of opportunity costs to human society and the less quantifiable losses associated with simplification of natural ecosystems.

In the case of both global warming and reduction of biological diversity, man is affecting nature in an unprecedented fashion, on a global scale, and with unpredictable and frequently irreversible results. This paper summarizes salient reasons for scientific concern about these two general issues and discusses some of the linkages between them and effects they are likely to have on life on earth.

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Global Change

Thanks in part to the spectacular summer of 1988, what was not too long ago a matter of some arcane concern among a small group of atmospheric scientists has grown to an issue that has engaged the attention, imagination, and fears of the general public. Between the development of scientific concern and the heat and drought of the summer of 1988, cover stories in the weekly news magazines, hundreds of newspaper and magazine articles here and abroad, and even the earth as the *Time* Planet of the Year (*2*), the general public has come to realize that something of some considerable significance may be going on.

Our understanding of how atmospheric composition affects global climate is still dramatically limited, but if our assumptions regarding the increase in concentrations of CO_2 and other anthropogenic greenhouse gases are true, the average global temperature will see a substantial rise. Although we do not yet have the tools that would allow us to predict with confidence the precise regional and local distribution of the temperature and precipitation conditions that constitute this global average, we can be certain that if, in fact, the projected global warming is realized in anything like the predicted amount of time, the patterns of life on earth could be changed dramatically.

The origins of these intersecting issues in science are clear and can be traced in lines that, in climate change, begin with the work of Arrhenius a century ago, to the concerns of scientists during the 1957 International Geophysical Year that led to the development of a network to monitor atmospheric carbon dioxide, to the ongoing work of contemporary climate modelers and atmospheric scientists. The biological concerns arose independently from nineteenth century natural history and the early conservation movement. Subsequently, these issues captured the interest of academic ecologists and other biological scientists across this country and elsewhere in the world as the potential of climate change to perturb fundamental assumptions about the stability of the environment became clear. Many of these scientists, in turn, have attempted to arouse the concern of the political community.

Much of early global climate science dealt with the atmospheric chemistry and physics necessary to understand the phenomenon. Fortunately, a number of biological scientists maintained a cross-disciplinary association with the climate scientists, especially a few with wide-ranging minds, and as the climate science developed, so did the concern for the possible implications of climate change. This interaction helped raise the public consciousness of the issue. Although the public was little taken with the esoteric aspects of atmospheric sciences, the concern with those implications was very real. What is intriguing is that here, in a situation unusual in recent environmental history, the first emergence of concern for an environmental problems grew from perceived threats to our ecological stability rather than first-order threats to human health. Let us examine some of those potential changes.

Climate and Ecology

First, it is reasonable to ask how we can begin to make predictions about ecological change. It can be done, in part, because we have the luxury of looking at the past. Paleontological fossil, pollen, and tree ring information as well as historical documents and records allow us to determine the past distribution and abundance of many animals and plants. Our knowledge of mechanism informs us that these are in large measure determined by regional temperature patterns and moisture patterns. Studies of paleobiology indicate that plants and animals are exquisitely sensitive to changes in climate (*3,4*). Where climate becomes unsuitable, life forms disappear. In some cases, they colonize other areas if the new climate and environment meet their needs (*5*). It is reasonable to expect that, in a gross sense, biota will respond in the future in ways similar to the past (*3*).

Even if we evaluate the issue in the context of conservative estimates in both the amount and rate of projected warming, we still face a serious global biological threat. Even the conservative general circulation model-derived estimate of a 3 °C rise yields an average temperature warmer than the planet has been for many tens of thousands of years (*6*).

Not only would this be a large warming, but models suggest it would be extraordinarily rapid—at least 10 and perhaps 100 times faster than in the past (*7*). Our first concern is that such a rate of change may overwhelm the ability of biota to adapt. The likelihood is that many species will disappear locally, and many more will become extinct. Biodiversity on the planet, the diversity of habitat and ecosystems, of species and genetic diversity will all be dramatically reduced.

Such warming alone could be a problem, but research has indicated that warming will not occur independently of other phenomena. Such a warming would likely be accompanied by dramatic changes in global rainfall patterns (*8*). These in turn would affect soil chemistry in addition to the direct effect of each on biota. Similarly, because we base our projections on a rise in CO_2 levels, it is important to remember that CO_2 itself affects plant growth, and not to the same extent in each species (*9*). As a result, the relative abundance of species, and thus the composition of ecological communities will change. In addition, the phenomenon that has garnered perhaps the greatest degree of public attention, sea level rise, may well wreak havoc on those coastal communities which we are now working so hard to preserve.

Further, in the context of climate generalities, it is important to remember that climate change will not be distributed uniformly around the globe. We now believe that a disproportional warming will take place at higher latitudes (*8,10*). Thus arctic communities would see the greatest stress and experience the greatest change; boreal forests, models suggest, are projected to decrease in extent dramatically (*5*). Whereas today most of our concerns are directed toward the biologically diverse tropics threatened by alterations in habitat, it appears that the high latitudes are in far greater damage from climate change.

Biofeedbacks

One other point that particularly concerns the high latitudes deserves emphasis: the importance of biofeedbacks. As we gain a better understaning of the earth–atmosphere system, we are beginning to realize that some of the effects of change are also causes of change.

Changes in biota will affect albedo, and thus the earth's radiation balance. It has been estimated that burning tropical rainforests may be responsible for 20% of the excess carbon in the atmosphere (*6,11,12*). In turn, a deforested earth has a dramatically reduced photosynthetic potential. Changes in biota will affect the ability of plants to serve as a carbon sinks.

Another effect of warming, particularly in the northern latitudes, is similar to the problem on might encounter were one to miswire a home thermostat. Rather than homeostatically damping change, warming would accelerate it. This is in part the result of the possibility that the greenhouse gas methane would be released from melting permafrost and arctic bogs (*13*).

A final general point is similar to one that has been raised in the context of human health protection. Climate is intrinsically variable, and as such incorporates extreme events such as droughts, hot spells, monsoons, lightning storms, and the like. These may have greater implications for biota than average change, and it is important to remember that some scientists predicted that an increase in the frequency of extreme events will accompany climate change.

Ecological Consequences

There are clear implications of all of this for life on earth. Should climate change occur, the future ranges of species will be dramatically different than today's. Tree species in the eastern United States, for example, would have to shift northward by some 500 to 700 km to adjust to changing climate regimes (*14,15*). Beech trees, which now grow in the east from Florida to Southern Canada would have to shift northward to a new range from New England to Hudson Bay. Sugar maples would leave most of the eastern United States. Hemlock and birch would have to undergo similar radical changes. But could they? When temperatures rose 3 to 5° at the end of the pleistocene glaciation, beech forests moved less than 20 miles per century—well under one-tenth of the predicted change (*14*).

In general, it is likely that the composition of communities will change. Species may move in the same direction, but they do not do so at the sime rates. As a result, shifting forest ranges would also affect animals. Many species depend on complex relationships between soils and several other species of animals and plants. In addition, the theoretical notion of northward migration may be illusory. Soils, for example, in the predicted new location, may not support the immigrating species. Some animals might respond by moving up in elevation rather than north in latitude, but they will only be successful if appropriate flora move up as well. Because the tops of mountains are smaller than the bottoms, populations will, of necessity, decrease. Current high elevation species may have nowhere to go.

One analysis yields the conclusion that with a 3° change, the great basin will lose 44% of its mammals, 23% of its butterflies, and perhaps one-fifth of its birds (*16*). Many other scientists have performed similar evaluations for different parts of the world, and predicted trends share directional characteristics.

Greenhouse Benefits

To be fair, I should note that this pessimism is not universal. The love of the natural world, although shared almost universally, is not always overriding. There is one scientist who speaks with some fervor of greenhuse warming as the "garden of Eden effect" (*17*). Some agricultual scientists are examing the increase in productivity that would result from a CO_2-enriched atmosphere (*18–20*). We must also note that CO_2 enrichment does not occur alone. Ongoing agricultural studies, for example, examine the interactins of CO_2, CH_4, and UV-B radiation, the intensity of which is controlled by stratospheric ozone, which reacts with cholorfluorocarbon greenhouse gases. Teasing out such interrelationships is a challenging task (*21*). Nevertheless, on a global scale, the biological disruptions resulting from climate change are likely to far outweigh any potential benefits.

Ecological Change: Accelerating Evolution

Plants and animals evolve, as do the comminities in which they live. Population and range constantly change. Paleoecological studies suggest that it is reasonable to expect a reassortment of species, communities, and habitats as climate changes (*3*). Success in adapting to change will be dependent on species ability to move with the changing climate by dispersing colonists. In North America, these will have to move north or up. If all of a species' habitat becomes unsutable and barriers to migration are present, extinction may result.

Are species' dispersal abilities adequate? Considering the biology of the species and the projected rates of change, it is unlikely that most could do so without human help. In addition, the problem is complicated by obstacles or physical barriers to migration. Man has made dramatic physical changes in the landscape he found. Managed agricultural lands, cities, artificial lakes, roads, parks, golf courses, or any number of anthropogenic land use changes threaten the ability of species to react successfully. We may well see a next century in which most surviving species are found only in small patches of their original habitats, isolated by larger expanses of human landscapes.

Such shifts are not mere abstractions. Think for a moment of national parks or wildlife refuges around the world. We have preserved these lands because of some unique characteristics, more often than not, various plants, animals, and communities that for some reason we chose to treasure. If their biota are forced to migrate, they face a habitat that, even if available, offers none of the protection that they have enjoyed. We may well be doomed to lose our most cherished places (*22*).

Biodiversity

In the last few, years, biodiversity has become one of the new watchwords of the environmental community. We recognize the abundance and variety of life on earth as a valued resource for reasons that range from the pragmatic, such as the provision of life-giving medicines, to the sublime, such as the sutisfaction we find in contemplating the beauty, mystery, and variety of life about us. Until lately, most of our concern has been focused on the tropics: the incredibly lush, rich, and diverse rainforests, where orders of magnitudes more species exist than anywhere else on earth. There the problem is primarily one of loss of habitat, losses which can be attributed to a variety of social and economic factors. Now we realize that climate will have a similar effect on biodiversity, perhaps on a percentage basis even greater. And as a result, we see the threat of dramatic changes in the composition of natural communities in the temperate and northern latitudes as well.

Ecology and Human Health

Climate change is unusual as an environmental issue in that the first scientific concerns and governmental responses were geared to threats other than those to human health. Traditionally, societal response to threats to human health are different from those that threaten the more abstract ecology, environment, or nonhuman species. Our environmental laws tend to differentiate carefully between the two.

Historically, direct threats to human health and the protection of our environment really were two different issues. Professionally, the public health community concerned with the control of disease and an environmental community concerned with wilderness and preservation issues had little in common. Although one can find direct relationships between human health and the conservation of biodiversity, they have not yet broadly affected the relationship between the two professions. One might, for example, postulate a scenario in which developed or managed land was allowed, in a restoration effort, to revert to scrub or woodland, which in turn would create a benevolent habitat for ticks and thus effect the epidemiology of Lyme disease.

Less speculative is the fact that the environmental movement of the last two decades has pulled the two communities together as we see that threats we face are common to both constituencies. This commonality of purpose has allowed us to make extraordinary progress in dealing with many environmental problems.

Outlook

Unfortunately, in the case of the global greenhouse, the fortuitous, straightforward technical solution does not present itself. The radiatively important trace gases are central to the processes that support our societies and our very lives, and with one exception, the chlorofluorocarbons, they cannot be eliminated. The best the scientists have been able to do so far, and it is a great deal, is identify the problem, estimate the possible physical and biological consequences and their probabilities, and project the potential rates of occurrence under different scenarios. Social scientists have worked with the natural scientists to develop those scenarios depending on assumptions about technological developments and the ability of different societies to make changes, some fundamental and some fairly simple.

But if and until major technological developments occur, almost all these changes are social changes: changes in the way we live, changes in our expectations of our institutions, of each other and of ourselves—changes in our values. There is much that we can do as scientists in improving our understanding of the issue and in helping cope with it, but insofar as we examine its root causes, I fear we are dealing with issues that are not the usual grist for the mills of either health scientists or ecologists, and we must assure collaboration with others in seeking solutions.

Conclusion

Climate change and worldwide loss of biodiversity are issues of global scope and importance that have recently become subjects of considerable public concern. Both issues are intriguing, in that their perceived threat lies in their potential to disrupt ecological functioning and stability rather than from any direct threat they may pose to human health.

We have seen that these issues are linked in a variety of ways. Wild communities, for instance, are likely to dramatically change in composition as their individual components respond to climate change with different migration rates and changes in reproductive physiology. Shifting vegetation zones will make previously suitable park and reserve sites less habitable than formerly for rare and threatened species, and a narrowing world genetic base will limit the capability of breeders to develop stress-resistant crop varieties.

Interdisciplinary scientific inquiry can help us identify and understand the nature of these issues and project what they may mean for life on earth under different scenarios, but science alone cannot provide adequate solutions. In arriving at solutions to these problems, we must look further afield at the linkages between environment and society and the value changes that may be necessary in order to fashion economic growth modes that do not ultimately jeopardize the health of the biosphere as a living system.

The views represented in this paper are those of the author and do not necessarily represent those of the United States Environmental Protection Agency.

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